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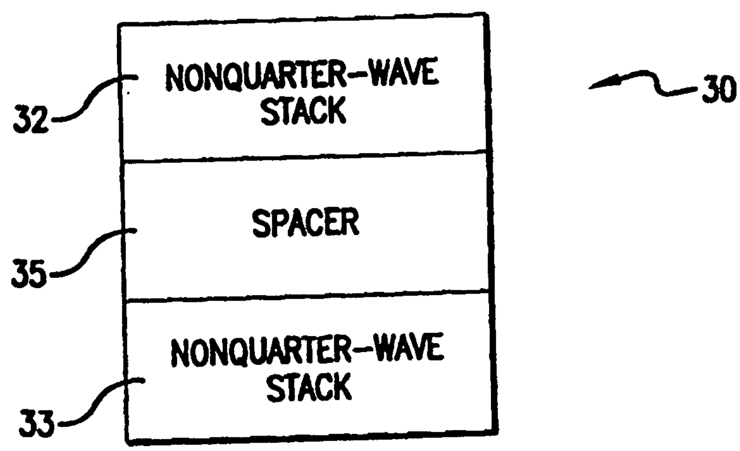
(54) Title: OPTICAL INTERFERENCE FILTER

(57) Abstract

An optical interference filter having high transmissivity at first and second passbands. The interference filter comprises a first stack having a plurality of dielectric layers, a second stack having a plurality of dielectric layers, and a spacer interposed between the first and second stacks. Each of the dielectric layers included in the first and second stacks have optical thicknesses which vary quadratically. The dielectric layers have alternating high and low refractive indices.



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OPTICAL INTERFERENCE FILTER

FIELD OF THE INVENTION

The present invention relates generally to optical interference filters. More particularly, the present invention relates to a dual bandpass optical interference filter capable of transmitting optical channels within a first and second passbands.

BACKGROUND OF THE INVENTION

Optical interference filters rely on principles of interference that modify reflected intensities of light incident on a surface. A familiar example of interference is the colors created when light reflects from a thin layer of oil floating on water. Briefly stated, by modifying the interface of a substance and its environment with a third material, reflectivity of the substance can be significantly altered. This principle is used in the fabrication of optical interference filters. These filters can be used as one of, or as the main filtering element in optical add/drop multiplexers employed in optical communication systems to select one or more channels from a transmission signal.

In its most simple form, an optical interference filter includes a cavity which is comprised of two partial reflectors separated by a spacer. Each partial reflector, also referred to as a quarter-wave stack, is typically constructed by depositing alternating layers of high and low refractive index dielectric materials upon a substrate where each layer has an optical thickness (defined as: physical thickness x refractive index) of a quarter wave ($\lambda/4$) at the desired wavelength of the filter. The spacer is typically a half-wave (or multiple half-wave) layer. An interference filter has an associated transmission characteristic which is a function of the reflectance of the layers of high and low index materials associated with the stack.

In many applications, optical interference filters are constructed using multiple cavities. Typically, cavities are deposited on top of other cavities, with a quarter-wave layer of low index material therebetween. Multicavity filters produce transmission spectra that are preferred in optical communication systems where sharp slopes and square passbands are needed to select one or more optical channels. The larger the number of cavities employed, the steeper the slope of the transmission bandwidth associated with a particular filter. The transmission bandwidth of a multicavity filter is wider as compared with the transmission bandwidth associated with a single cavity filter.

FIG. 1 illustrates an exemplary transmission spectrum (normalized to 1.55 μm) for a quarter-wave stack having a plurality of high/low refractive index dielectric layers . The stack is tuned to reject wavelengths in the 1.5μm range and exhibits ripple sidelobes referenced at 5.

FIG. 2 is an exemplary transmission spectrum (normalized to 1.55 μm) for a single cavity optical interference filter utilizing a pair of stacks each having the transmission spectrum shown in Fig. 1. As can be seen in FIG.2 the transmission response is acceptable at λ/λ_0=1.0 which corresponds to 1.55μm (λ/λ_0=1.55μm/1.55μm). However, the response at .845 which corresponds to approximately 1.31μm (λ/λ_0=1.31μm/1.55μm) falls on the sideband and/or within the ripple band of the transmission spectrum, thereby making transmission of a particular wavelength in this range unreliable. More specifically, the single cavity interference filter produces high transmittance at wavelengths referenced at 10, but also produces relatively low transmittance as referenced at 15. Thus, transmission at wavelengths in the 1.5μm range may be reliable while transmission for wavelengths within the ripple band or sideband slope are subject to variations in the transmission characteristic. This is also true for wavelengths in the 1.6μm range (λ/λ_0=1.62μm/1.55μm). FIG. 2 demonstrates that interference filters typically provide a single reliable passband.

As noted above, optical systems can utilize one or more interference filters to select particular channels from a transmission signal. For example, a first filter may be used to select a pay-load channel associated with voice and/or data transmission in the 1.5μm range and a second filter is used to select a service channel in the 1.3μm or 1.6μm range which carries system level and/or network monitoring information. The use of two separate filters, however, has several disadvantages. First, it increases overall system cost since it requires the manufacture and installation of two individual components. Secondly, optical networks typically have a predetermined loss budget, if exceeded, can compromise signal integrity. Each component, in this case an optical filter, contributes some loss to the overall network. By using two separate filters to select a payload channel and a service channel, each filter negatively impacts a network's loss budget.

Thus, there is a need for a filtering element used with optical communication systems capable of selecting a first and a second optical passbands. There is a further need to provide such a filtering element which reliably selects at least one wavelength corresponding to a payload channel as well as a wavelength corresponding to a service channel within an optical network.

SUMMARY OF THE INVENTION

The invention meets these needs and avoids the above-referenced disadvantages by providing an optical interference filter that is capable of selecting a first and second optical passbands. An optical interference filter is provided which comprises a substrate having a surface and a first stack deposited on the substrate surface. The first stack includes a first plurality of dielectric layers where each of selected ones of the first

plurality of dielectric layers has a respective one of a plurality of first optical thicknesses. The plurality of optical thicknesses vary in a first direction with respect to the substrate. The interference filter further comprises a second stack which includes a second plurality of dielectric layers where each of selected ones of the second plurality of dielectric layers has a respective one of a plurality of second optical thicknesses. The plurality of optical thicknesses vary in the first direction with respect to the substrate. A spacer is interposed between the first and second stacks.

The foregoing, and other features and advantages of the present invention, will be apparent from the following description, the accompanying drawings and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a transmission spectrum (normalized to 1.55 μm) for an exemplary quarter-wave stack.

FIG. 2 illustrates a transmission spectrum (normalized to 1.55 μm) for a single cavity optical interference filter.

FIG. 3 schematically illustrates a quadratically chirped stack deposited upon a transparent substrate in accordance with the present invention.

FIG. 4 illustrates optical thickness values, in quarter-waves, for 15 dielectric layers included within the stack shown in FIG. 3 in accordance with the present invention.

FIG. 5 is a graphical illustration of the optical thickness values of the dielectric layers listed in FIG. 4.

FIG. 6 illustrates a normalized transmission spectrum for an exemplary 15 layer quadratically chirped stack in accordance with the present invention.

FIG. 7 schematically illustrates a single cavity interference filter in accordance with the present invention.

FIG. 8 illustrates optical thickness values, in quarter-waves for a single cavity interference filter in accordance with the present invention.

FIG. 9 is a transmission spectrum normalized to 1.55 μm for the single cavity interference filter described with reference to Fig. 7 in accordance with the present invention.

FIG. 10 illustrates optical thickness values, in quarter-waves, for 119 layers included within a single cavity interference filter in accordance with the present invention

FIG. 11 is a transmission spectrum for the single cavity interference filter described with reference to Fig. 10 in accordance with the present invention.

FIG. 12 is a graphical illustration of the optical thickness values of the dielectric layers listed in FIG. 10.

Detailed Description Of The Preferred Embodiments

The present invention provides an optical interference filter that has high transmittance (or reflectance close to zero) for a first and a second optical passbands. In one embodiment of the present invention, the interference filter is capable of selecting a wavelength corresponding to a payload channel in the 1.5 μm range and a second wavelength corresponding to a service channel in the 1.3 μm range. In another embodiment, the interference filter is capable of selecting a wavelength corresponding to a payload channel in the 1.5 μm range and a wavelength corresponding to a service channel in the 1.6 μm range. It should be understood that the present invention can be configured to select other wavelengths as well as passbands which include a plurality of optical wavelengths.

Turning to the drawings where like reference numbers indicate like elements, FIG. 3 schematically illustrates a fifteen layer stack 10 (also referred to as a mirror or partial mirror) deposited upon a transparent substrate 12 which can be, for example, glass, silica, etc. Stack 10 includes dielectric layers $13_1 \ldots 13_N$ where N=15 in this exemplary configuration. Each of the layers $13_1 \ldots 13_N$ alternates between a layer 13_1 with a high refractive index, such as Ta_2O_5 (refractive index = 2.05), and a layer 13_2 with a low refractive index, such as SiO_2 (refractive index =1.44). The number of dielectric layers as well as the materials selected as the dielectric layers which form stack 10 are dependent upon the bandwidth of the desired filter. Exemplary materials, in addition to the ones mentioned above, include, but are not limited to, TiO_2 (refractive index = 2.25), Al_2O_3 (refractive index = 1.6), HfO_2 (refractive index =1.971), ZrO_2 (refractive index = 2.035), etc.

Dielectric layers $13_1 \ldots 13_N$ have optical thickness values which are quadratically chirped. (Because Fig. 3 is a schematic representation of a fifteen layer stack, the optical thicknesses of the layers shown are not to scale.) To describe what is meant by quadratically chirped, Fig. 4 illustrates exemplary optical thickness values (t_n) for each of the fifteen dielectric layers $13_1 \ldots 13_{15}$ included in stack 10. It should be understood that these thicknesses are provided for illustrative purposes only with respect to exemplary passbands. As can be seen, layers 13_1 and 13_{15} have substantially the same optical thickness, layers 13_2 and 13_{14} also have substantially the same optical thickness and so on

until layer 13_8, which is the center layer and does not have a corresponding symmetric layer. The thickness of each layer varies based on the following equation:

$$t_n = 1 + 0.15\left[\frac{\frac{(N-1)}{2} - n + 1}{\frac{(N-1)}{2}}\right]^2 \qquad (1)$$

where t_n is the resulting optical thickness associated with a particular layer, N is the total number of layers used to form an individual stack or mirror and n is the number of the particular layer within the stack. The quadratic chirping of the dielectric layers comprising a stack results in layers having substantially non-quarter wave optical thicknesses. FIG. 5 is a graphical representation of the dielectric layer optical thicknesses of stack 10 shown in FIG. 4 and in accordance with equation (1). As seen in FIG. 5, the graph has a somewhat concave shape, and hence equation (1) is referred to as a concave stack. It should be understood that adjacent layers within the quadratically chirped stack can have substantially equal optical thicknesses while retaining this considerable concave shape.

FIG. 6 illustrates a transmission spectrum normalized to 1.55µm for the exemplary fifteen layer quadratically chirped stack 10 represented by equation (1). For normalized wavelength values from approximately .9 to 1.2 (1.5µm range), stack 10 has a low trasmittance or high reflectance. However, in the 1.3 µm range, referenced at 20, stack 10 produces a high transmission characteristic with almost no ripple. Exemplary stack 10 with this transmission spectrum can be used as a partial mirror within an interference filter tuned to transmit a passband in the 1.3µm range.

Fig. 7 schematically illustrates a single cavity interference filter 30 comprising a first stack 32 and a second stack 33 separated by spacer 35. The spacer can be a material with a low refractive index, such as SiO_2 (1.44). In accordance with the present invention, each of the stacks 32, 33 are quadratically chirped using equation (1). Fig. 8 illustrates exemplary optical thickness values (t_n) for a thirty one layer (M) single cavity interference filter where dielectric layers 1-15 form first stack 32, layer 16 corresponds to the low index spacer 35, and layers 17-31 form second stack 33. The symmetrical optical thickness values of these quadratically chirped layers is demonstrated by layers 1 and 15 which have substantially the same optical thickness (1.1500000), layers 2 and 14 which have substantially the same optical thickness (1.1102041), and so on for first stack 32. Similarly, layers 17 and 31 have substantially the same optical thickness (1.1500000), layers 18 and 30 have substantially the same optical thickness (1.1102041) and so on for second stack 33. Again, it should be understood that these optical thicknesses are

provided for illustrative purposes only. In addition, when applying equation (1) to determine the optical thickness of each layer included in a cavity, it is important to point out that "N" refers to the number of layers in a stack and not to the number of total layers "M" in the cavity. Likewise "n" refers to the particular layer number in a stack and not to the layer number "m" within a cavity. For example, Fig. 8 lists 31 layers in the cavity, but for m=18, n=2 in equation (1) because the eighteenth layer in the cavity corresponds to the second layer in the second stack comprised of layers 17-31. Similarly, for m=30, n=14 because the thirtieth layer in the cavity corresponds to the fifteenth layer in the second stack.

FIG. 9 is an exemplary transmission spectrum normalized to 1.55 μm for the single cavity, thirty one layer, interference filter shown in Fig. 7. As can be seen, a high transmission spike is present at $\lambda/\lambda_0=1.0$ which corresponds to a wavelength in the 1.5 μm range (approximately 1550nm) and a relatively ripple-free transmission characteristic at approximately .845 which corresponds to a wavelength in the 1.3 μm range (approximately 1310nm). Thus, a single cavity interference filter with a pair of quadratically chirped stacks provides high transmittance at a first passband in the 1.5μm range and at a second passband in the 1.3μm range which can correspond to a payload channel wavelength and a service channel wavelength, respectively, within an optical network.

The interference filter in accordance with the present invention can also be formed by depositing cavities having quadratically chirped stacks on top of other cavities having quadratically chirped stacks. For example, the thirty one layer single cavity filter 30 described with reference to Fig. 7 can be deposited on top of another cavity, and so on, to form a multi-cavity interference filter. An additional coupling layer is deposited between the cavities. The resulting transmission spectrum for such a multi-cavity filter broadens the transmission of wavelengths in the 1550nm range while retaining the relatively ripple-free transmission characteristic corresponding to wavelengths in the 1310nm range. This is beneficial because the sharp peak at 1 of Fig. 9 is too narrow to tune a particular optical source associated with a payload channel wavelength (1.5μm range).

In another embodiment of the present invention, an interference filter provides transmission for a first passband in the 1.5μm range corresponding to a payload channel wavelength and for a second passband in the 1625nm range corresponding to a service channel wavelength. The alternative embodiment is based on the following equation:

$$t_n = 1 - 0.06 \left[\frac{\frac{(N-1)}{2} - n + 1}{\frac{(N-1)}{2}} \right]^2 \qquad (2)$$

where t_n is the optical thickness associated with a particular layer, N is the total number of layers used to form an individual stack or mirror and n is the number of the particular layer within the stack. In this embodiment, the wavelength distance from the payload channel range (1550 nm) to the service channel range (1625 nm) is approximately 75 nm. This is much shorter as compared to the distance between the same payload channel and the service channel in the 1.3μm range which is approximately 240 nm. Because of this short distance, equation (2) includes a change in the magnitude of the chirp from 0.15 to .06. In addition, the number of layers in each cavity increases to approximately 119 where layers 1-59 form a first stack or mirror, layer 60 corresponds to a low index spacer material, and layers 61-119 form the second stack. Fig. 10 lists exemplary optical thickness values for the single cavity filter where layers 1-59 corresponds to the first stack, layer 60 corresponds to the spacer, and layers 61-119 correspond to the second stack.

FIG. 11 illustrates an exemplary transmission spectrum for the single cavity, 119 layer interference filter having the optical thickness values listed with reference to Fig. 10. As can be seen, a high transmission spike is present at approximately 1550nm while a relatively ripple-free transmission characteristic is present in the 1625nm range. Thus, a single cavity interference filter with a pair of quadratically chirped stacks provides high transmission at a first passband in the 1550nm range and at a second passband in the 1625nm range which can correspond to a payload channel wavelength and a service channel wavelength, respectively, within an optical network.

For illustrative purposes, FIG. 12 is a graphical representation of the optical thickness values for the dielectric layers listed in Fig. 10 producing a graph with a somewhat convex shape.

Again, the interference filter can also be formed by depositing cavities having quadratically chirped stacks on top of other cavities having quadratically chirped stacks similar to the configuration shown in Fig. 7. For example, the 119 layer cavity described with reference to Fig. 11 can be deposited on top of another cavity with a coupling layer therebetween to form a multi-cavity interference filter. The resulting transmission spectrum for such a multi-cavity filter broadens the transmission of wavelengths in the

1550nm range shown in Fig. 12 while retaining the relatively ripple-free transmission characteristic corresponding to wavelengths in the 1310nm range. The multi-cavity filter increases and squares the passband associated with the payload channel wavelengths while retaining the relatively ripple-free transmission characteristic associated with service channel wavelengths in the 1625nm range.

Although the invention has been particularly shown and described with reference to several embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined in the appended claims.

WHAT IS CLAIMED IS:

1. An optical interference filter comprising:

a substrate having a surface;

a first stack deposited on said surface of said substrate, said first stack including a first plurality of dielectric layers, each of selected ones of said first plurality of dielectric layers having a respective one of a plurality of first optical thicknesses, said plurality of optical thicknesses varying in a first direction with respect to said substrate;

a second stack including a second plurality of dielectric layers, each of selected ones of said second plurality of dielectric layers having a respective one of a plurality of second optical thicknesses, said plurality of optical thicknesses varying in said first direction with respect to said substrate; and

a spacer interposed between said first and second stacks.

2. The optical interference filter in accordance with claim 1 wherein said first plurality of optical thicknesses varying in accordance with:

$$t_n = 1 + 0.15 \left[\frac{\frac{(N-1)}{2} - n + 1}{\frac{(N-1)}{2}} \right]^2$$

where t_n corresponds to respective optical thicknesses of said selected ones of said first plurality of dielectric layers, N corresponds to a total number of said first plurality of dielectric layers and n corresponds to a particular one of said first plurality of dielectric layers.

3. The optical interference filter in accordance with claim 1 wherein said second plurality of optical thicknesses varying in accordance with:

$$t_n = 1 + 0.15 \left[\frac{\frac{(N-1)}{2} - n + 1}{\frac{(N-1)}{2}} \right]^2$$

where t_n corresponds to respective optical thicknesses of said selected ones of said second plurality of dielectric layers, N corresponds to a total number of said second plurality of dielectric layers and n corresponds to a particular one of said second plurality of dielectric layers.

4. The optical interference filter in accordance with claim 1 wherein said first plurality of optical thicknesses varying in accordance with:

$$t_n = 1 - 0.06 \left[\frac{\frac{(N-1)}{2} - n + 1}{\frac{(N-1)}{2}} \right]^2$$

where t_n corresponds to respective optical thicknesses of said selected ones of said first plurality of dielectric layers, N corresponds to a total number of said first plurality of dielectric layers and n corresponds to a particular one of said first plurality of dielectric layers.

5. The optical interference filter in accordance with claim 1, wherein said second plurality of optical thicknesses varying in accordance with:

$$t_n = 1 - 0.06 \left[\frac{\frac{(N-1)}{2} - n + 1}{\frac{(N-1)}{2}} \right]^2$$

where t_n corresponds to respective optical thicknesses of said selected ones of said second plurality of dielectric layers, N corresponds to a total number of said second plurality of dielectric layers and n corresponds to a particular one of said second plurality of dielectric layers.

6. The optical interference filter in accordance with claim 1 wherein each of said first plurality of dielectric layers comprising material of alternating high and low refractive index.

7. The optical interference filter in accordance with claim 1 wherein each of said second plurality of dielectric layers comprising material of alternating high and low refractive index.

8. The optical interference filter in accordance with claim 1 wherein said first plurality of dielectric layers are selected from the group consisting essentially of SiO_2, Ta_2O_5, TiO_2, Al_2O_3, HfO_2, and ZrO_2.

9. The optical interference filter in accordance with claim 1 wherein said second plurality of dielectric layers are selected from the group consisting essentially of SiO_2, Ta_2O_5, TiO_2, Al_2O_3, HfO_2, and ZrO_2.

10. The optical interference filter in accordance with claim 1 wherein said spacer is formed of a dielectric material having a low refractive index.

11. The optical interference filter in accordance with claim 1 wherein said filter has an associated transmission characteristic comprising a first and second passbands.

12. The optical interference filter in accordance with claim 11 wherein said first passband includes at least one optical channel having a wavelength in the 1.5μm range.

13. The optical interference filter in accordance with claim 11 wherein said second passband includes at least one optical channel having a wavelength in the 1.3μm range.

14. The optical interference filter in accordance with claim 11 wherein said second passband includes at least one optical channel having a wavelength in the 1.6μm range.

15. A multi cavity optical interference filter comprising:

a plurality of cavities, each of said cavities being separated by a coupling layer, each of said plurality of cavities comprising:

a first stack including a first plurality of dielectric layers, each of selected ones of said first plurality of dielectric layers having a respective one of a plurality of first optical thicknesses, said first plurality of optical thicknesses varying over a first group of said first plurality of dielectric layers;

a second stack including a second plurality of dielectric layers, each of selected ones of said second plurality of dielectric layers having a respective one of a plurality of second optical thicknesses, said second plurality of optical thicknesses varying over a second group of said second plurality of dielectric layers; and

a spacer interposed between said first and second stacks.

16. The multi cavity interference filter in accordance with claim 15 wherein said first plurality of optical thicknesses varying in accordance with:

$$t_n = 1 + 0.15 \left[\frac{\frac{(N-1)}{2} - n + 1}{\frac{(N-1)}{2}} \right]^2$$

where t_n corresponds to respective optical thicknesses of said selected ones of said first plurality of dielectric layers, N corresponds to a total number of said first plurality of dielectric layers and n corresponds to a particular one of said first plurality of dielectric layers.

17. The optical interference filter in accordance with claim 15 wherein said second plurality of optical thicknesses varying in accordance with:

$$t_n = 1 + 0.15 \left[\frac{\frac{(N-1)}{2} - n + 1}{\frac{(N-1)}{2}} \right]^2$$

where t_n corresponds to respective optical thicknesses of said selected ones of said second plurality of dielectric layers, N corresponds to a total number of said second plurality of dielectric layers and n corresponds to a particular one of said second plurality of dielectric layers.

18. The optical interference filter in accordance with claim 15 wherein said first plurality of optical thicknesses varying in accordance with:

$$t_n = 1 - 0.06 \left[\frac{\frac{(N-1)}{2} - n + 1}{\frac{(N-1)}{2}} \right]^2$$

where t_n corresponds to respective optical thicknesses of said selected ones of said first plurality of dielectric layers, N corresponds to a total number of said first plurality of dielectric layers and n corresponds to a particular one of said first plurality of dielectric layers.

19. The optical interference filter in accordance with claim 15 wherein said second plurality of optical thicknesses varying in accordance with:

$$t_n = 1 - 0.06 \left[\frac{\frac{(N-1)}{2} - n + 1}{\frac{(N-1)}{2}} \right]^2$$

where t_n corresponds to respective optical thicknesses of said selected ones of said second plurality of dielectric layers, N corresponds to a total number of said second plurality of dielectric layers and n corresponds to a particular one of said second plurality of dielectric layers.

20. The optical interference filter in accordance with claim 15 wherein each of said first plurality of dielectric layers comprising material of alternating high and low refractive index.

21. The optical interference filter in accordance with claim 15 wherein each of said second plurality of dielectric layers comprising material of alternating high and low refractive index.

22. The optical interference filter in accordance with claim 15 wherein each of said spacers is formed of a dielectric material having a low refractive index.

23. The optical interference filter in accordance with claim 15 wherein said filter has an associated transmission characteristic comprising a first and second passbands.

24. The optical interference filter in accordance with claim 23 wherein said first passband includes at least one optical channel having a wavelength in the 1.5μm range.

25. The optical interference filter in accordance with claim 23 wherein said second passband includes at least one optical channel having a wavelength in the 1.3μm range.

26. The optical interference filter in accordance with claim 23 wherein said coupling layer is a material having a high index of refraction.

27. The optical interference filter in accordance with claim 23 wherein said coupling layer is a material having a low index of refraction.

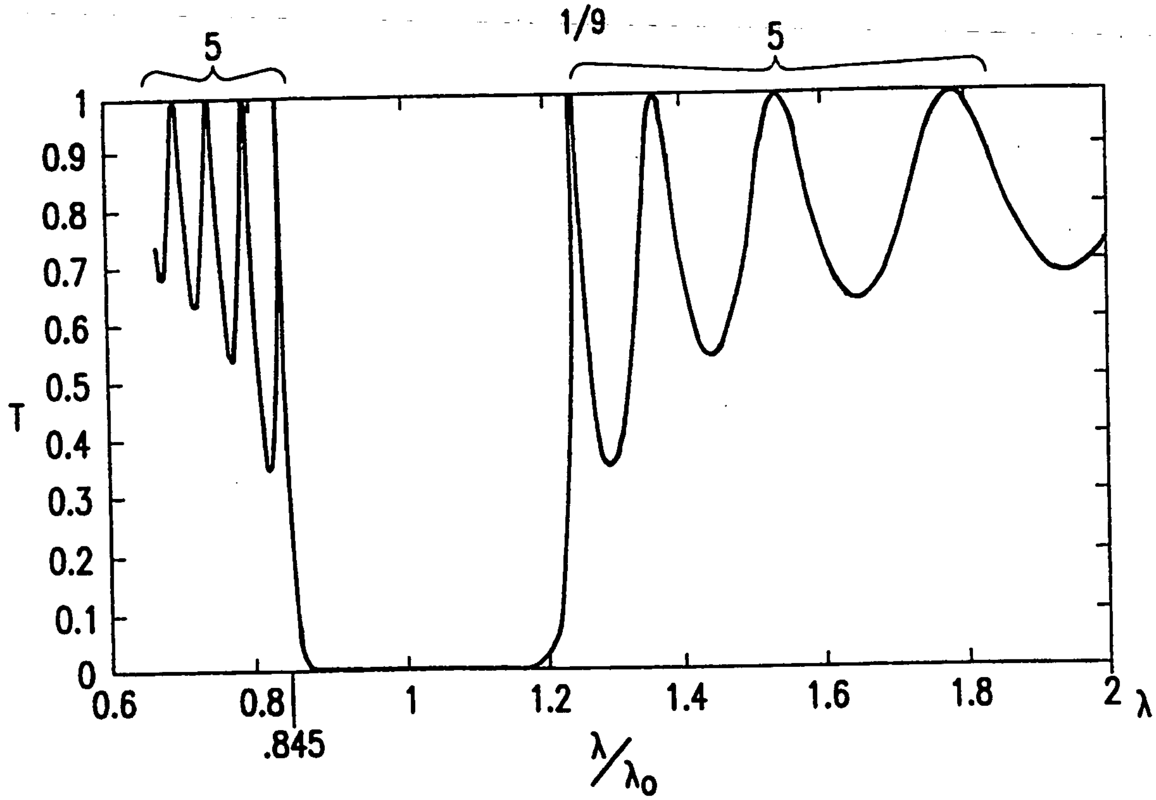

FIG.1

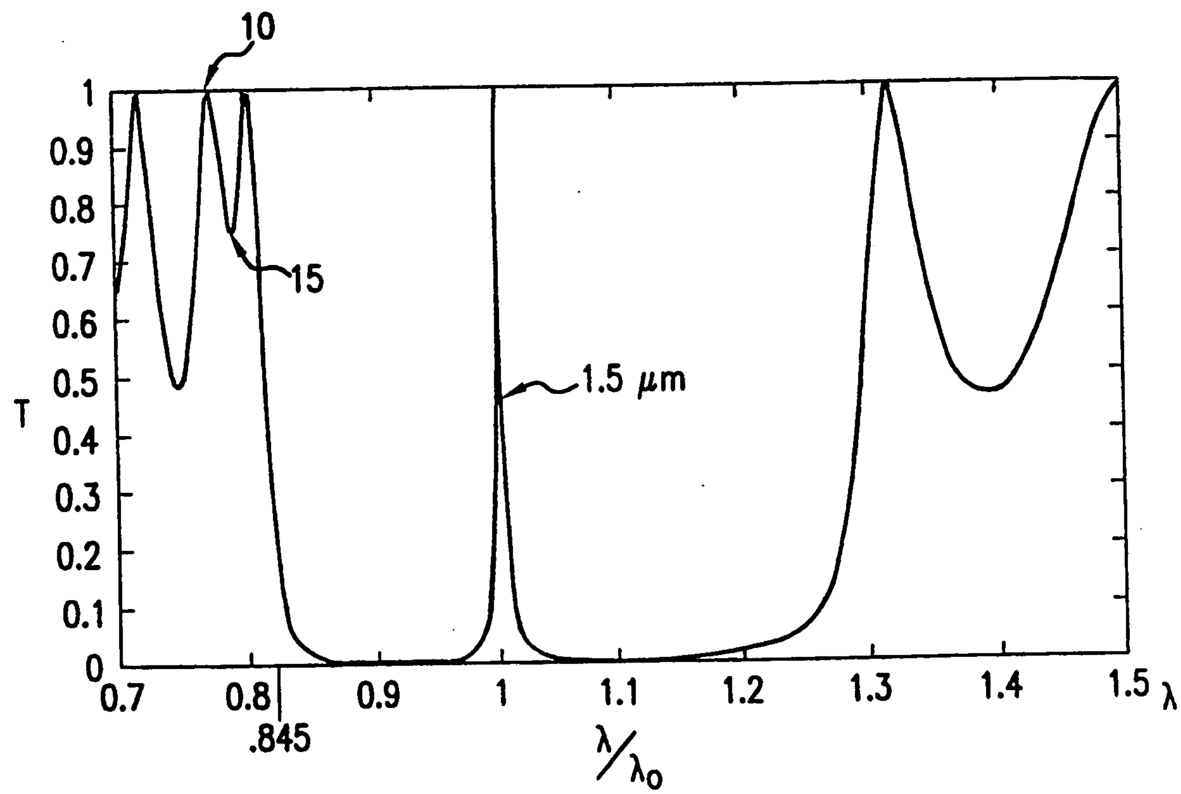

FIG.2

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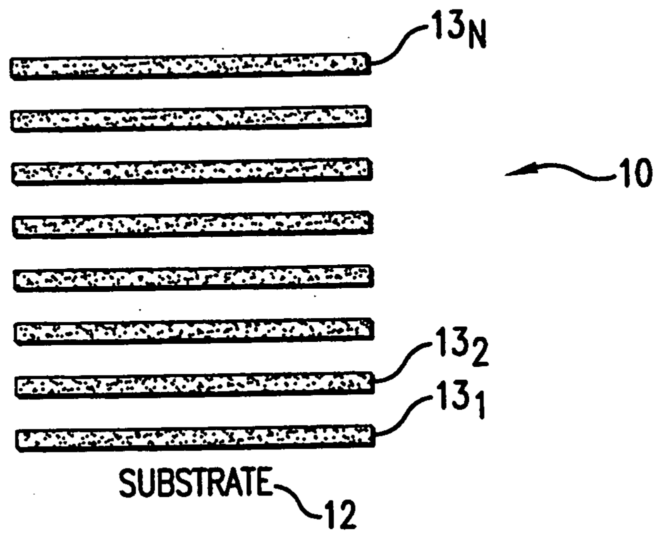

FIG.3

n	t_n
1	1.1500000
2	101102041
3	1.0765306
4	1.0489796
5	1.0275510
6	1.0122449
7	1.0030612
8	1.0000000
9	1.0030612
10	1.0122449
11	1.0275510
12	1.0489796
13	1.0765306
14	1.1102041
15	1.1500000

FIG.4

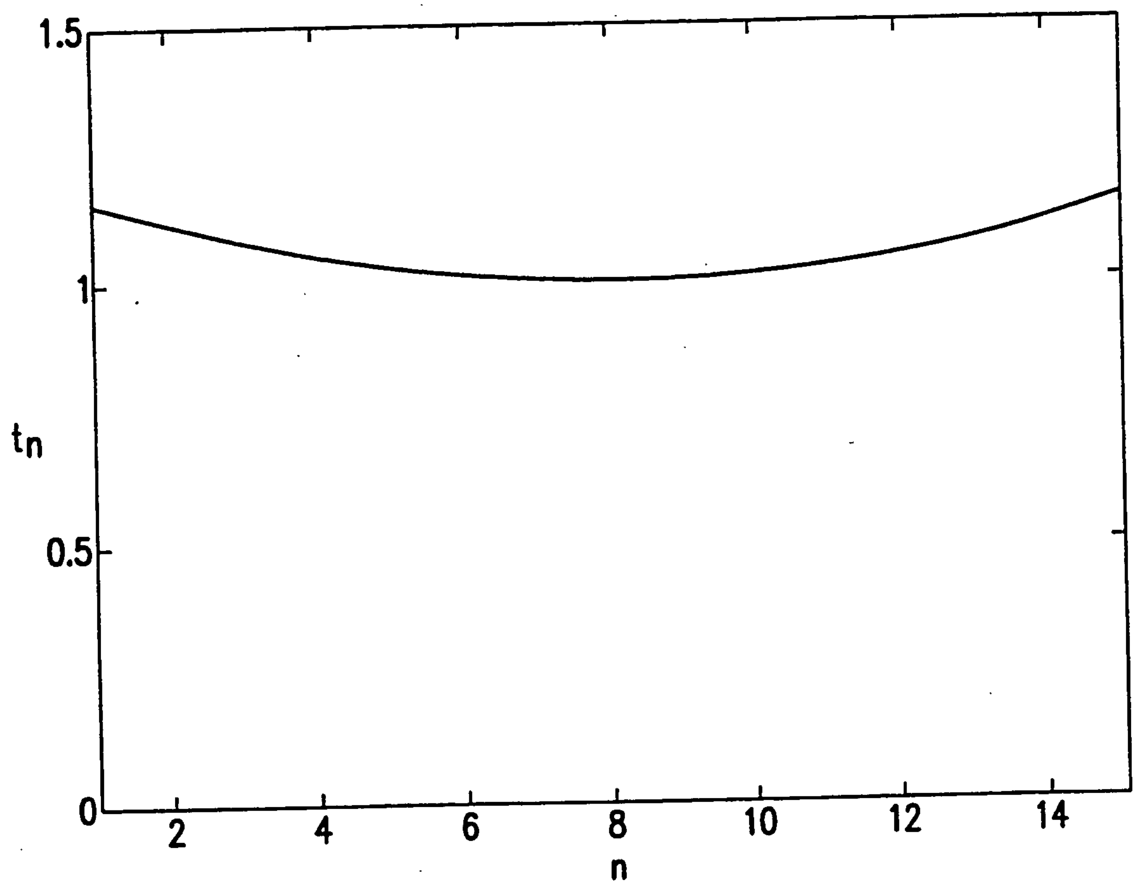

FIG.5

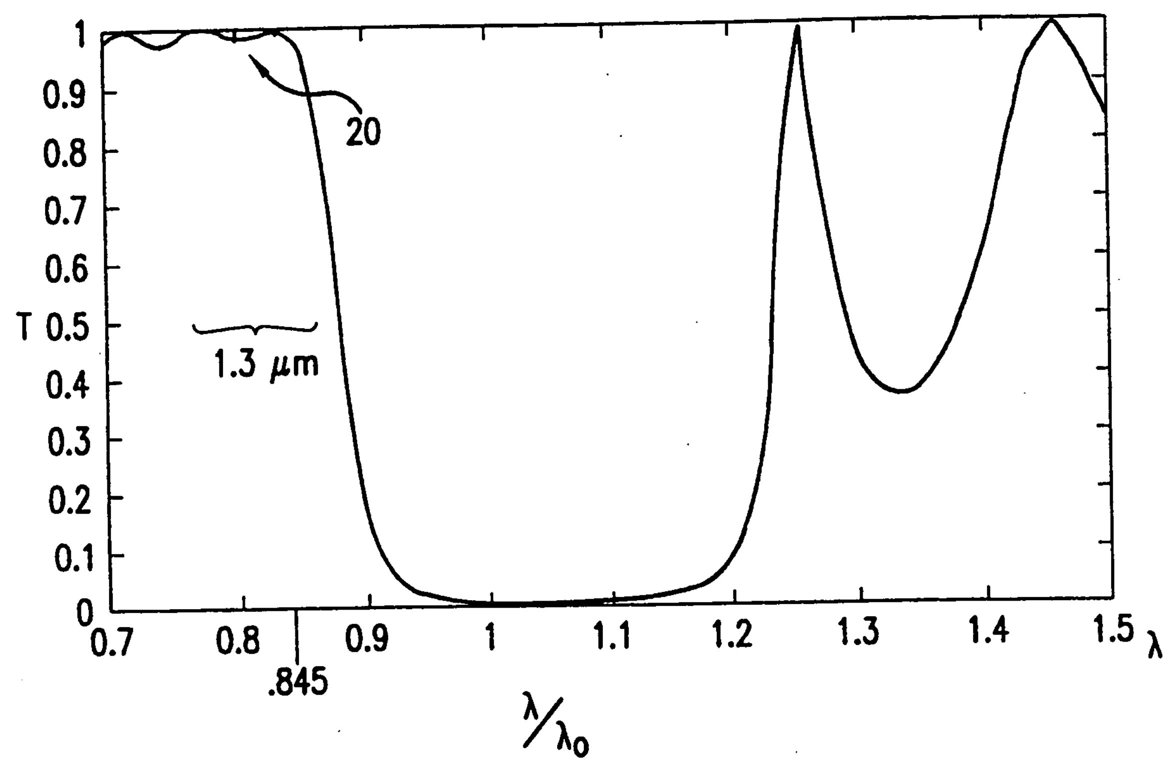
1
0.9
0.8
0.7
0.6
T 0.5
0.4
0.3
0.2
0.1
0
0.7
0.8
.845
0.9
1
1.1
1.2
1.3
1.4
1.5
λ
20
1.3 μm
λ/λo

FIG.6

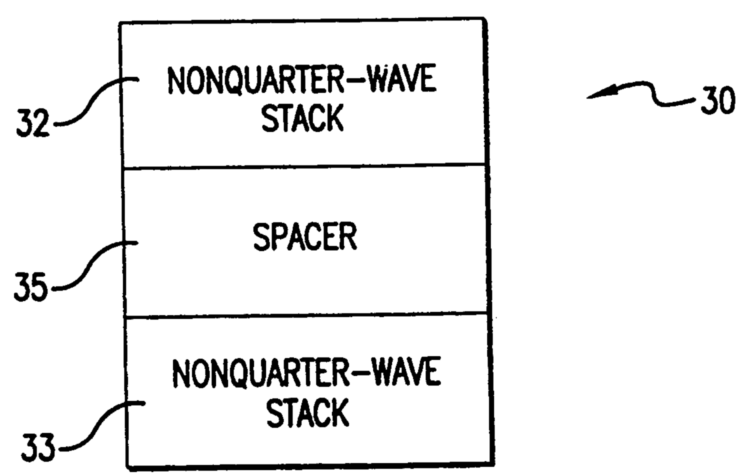
NONQUARTER-WAVE STACK
SPACER
NONQUARTER-WAVE STACK
32
35
33
30

FIG.7

m	t_m
1	1.1500000
2	1.1102041
3	1.0765306
4	1.0489796
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6	1.0122449
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19	1.0765306
20	1.0489796
21	1.0275510
22	1.0122449
23	1.0030612
24	1.0000000
25	1.0030612
26	1.0122449
27	1.0275510
28	1.0489796
29	1.0765306
30	1.1102041
31	1.1500000

FIG.8

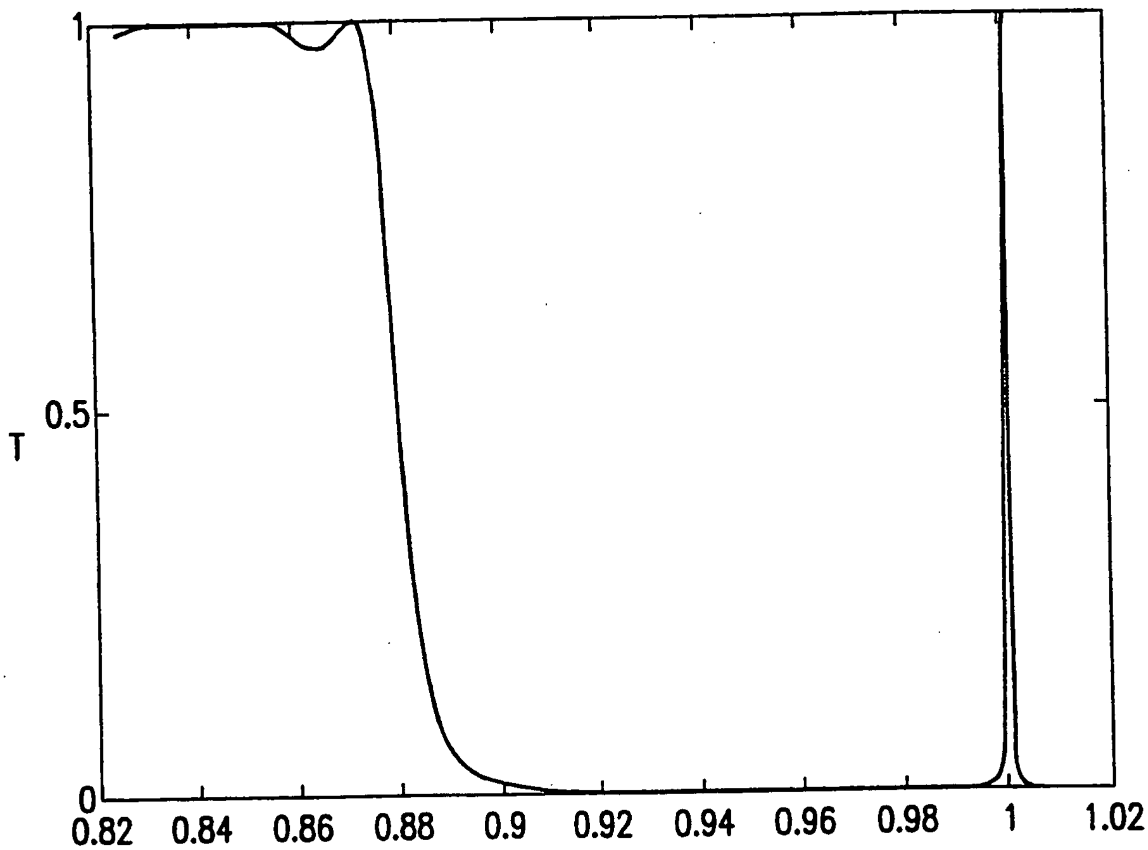

FIG.9

m	t_n
1	.94000000
2	.94406659
3	.94799049
4	.95177170
5	.95541023
6	.95890606
7	.96225922
8	.96546968
9	.96853746
10	.97146254
11	.97424495
12	.97688466
13	.97938169
14	.98173603
15	.98394768
16	.98601665
17	.98794293
18	.98972652
19	.99136742
20	.99286564
21	.99422117
22	.99543401
23	.99650416
24	.99743163
25	.99821641
26	.99885850
27	.99935791
28	.99971463
29	.99992866
30	.10000000
31	.99992866
32	.99971463
33	.99935791
34	.99885850
35	.99821641
36	.99743163
37	.99650416
38	.99543401
39	.99422117
40	.99286564
41	.99136742

m	t_n
42	.98972652
43	.98794293
44	.98601665
45	.98394768
46	.98173603
47	.97938169
48	.97688466
49	.97424495
50	.97146254
51	.96853746
52	.96546968
53	.96225922
54	.95890606
55	.95541023
56	.95177170
57	.94799049
58	.94406659
59	.94000000
60	2.6600000
61	.94000000
62	.94406659
63	.94799049
64	.95177170
65	.95541023
66	.95890606
67	.96225922
68	.96546968
69	.96853746
70	.97146254
71	.97424495
72	.97688466
73	.97938169
74	.98173603
75	.98394768
76	.98601665
77	.98794293
78	.98972652
79	.99136742
80	.99286564
81	.99422117
82	.99543401

m	t_n
83	.99650416
84	.99743163
85	.99821641
86	.99885850
87	.99935791
88	.99971463
89	.99992866
90	.10000000
91	.99992866
92	.99971463
93	.99935791
94	.99885850
95	.99821641
96	.99743163
97	.99650416
98	.99543401
99	.99422117
100	.99286564
101	.99136742
102	.98972652
103	.98794293
104	.98601665
105	.98394768
106	.98173603
107	.97938169
108	.97688466
109	.97424495
110	.97146254
111	.96853746
112	.96546968
113	.96225922
114	.95890606
115	.95541023
116	.95177170
117	.94799049
118	.94406659
119	.94000000

FIG.10

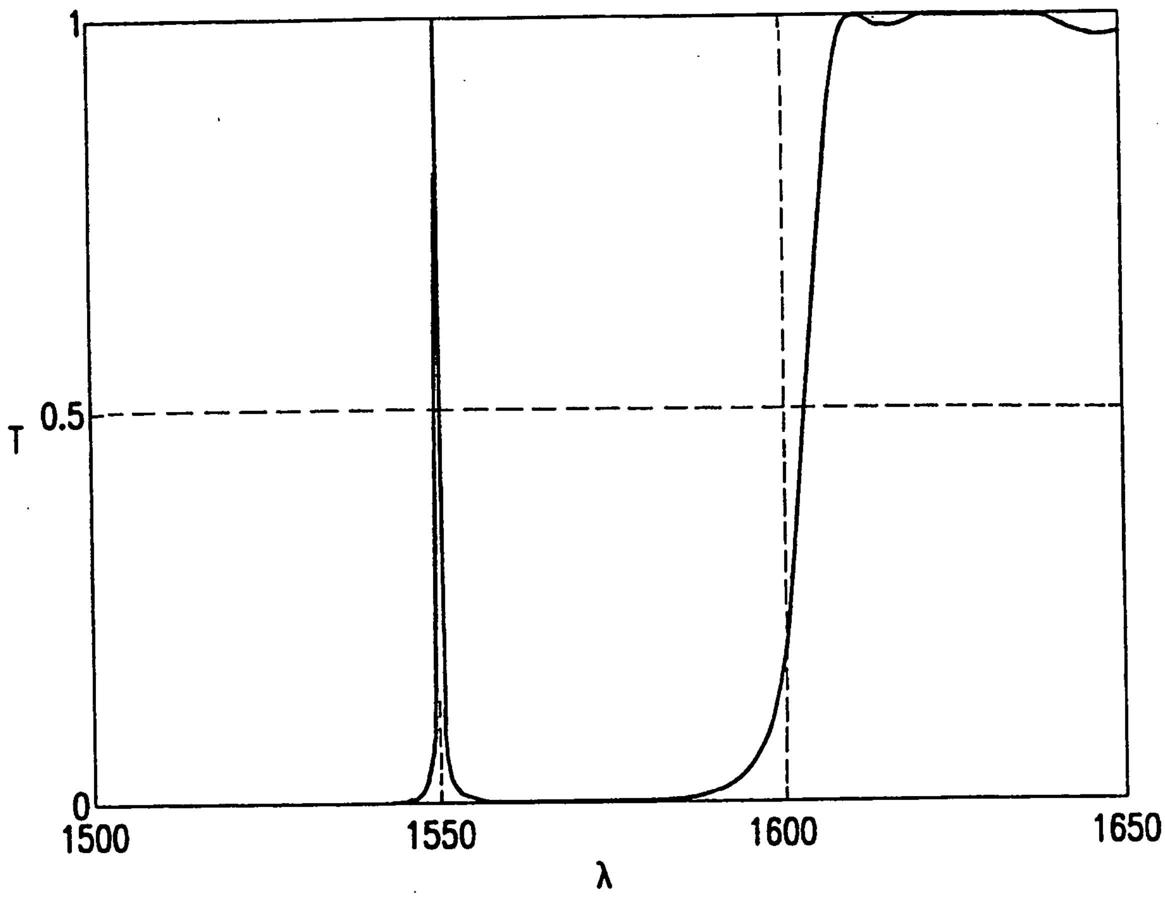

FIG.11

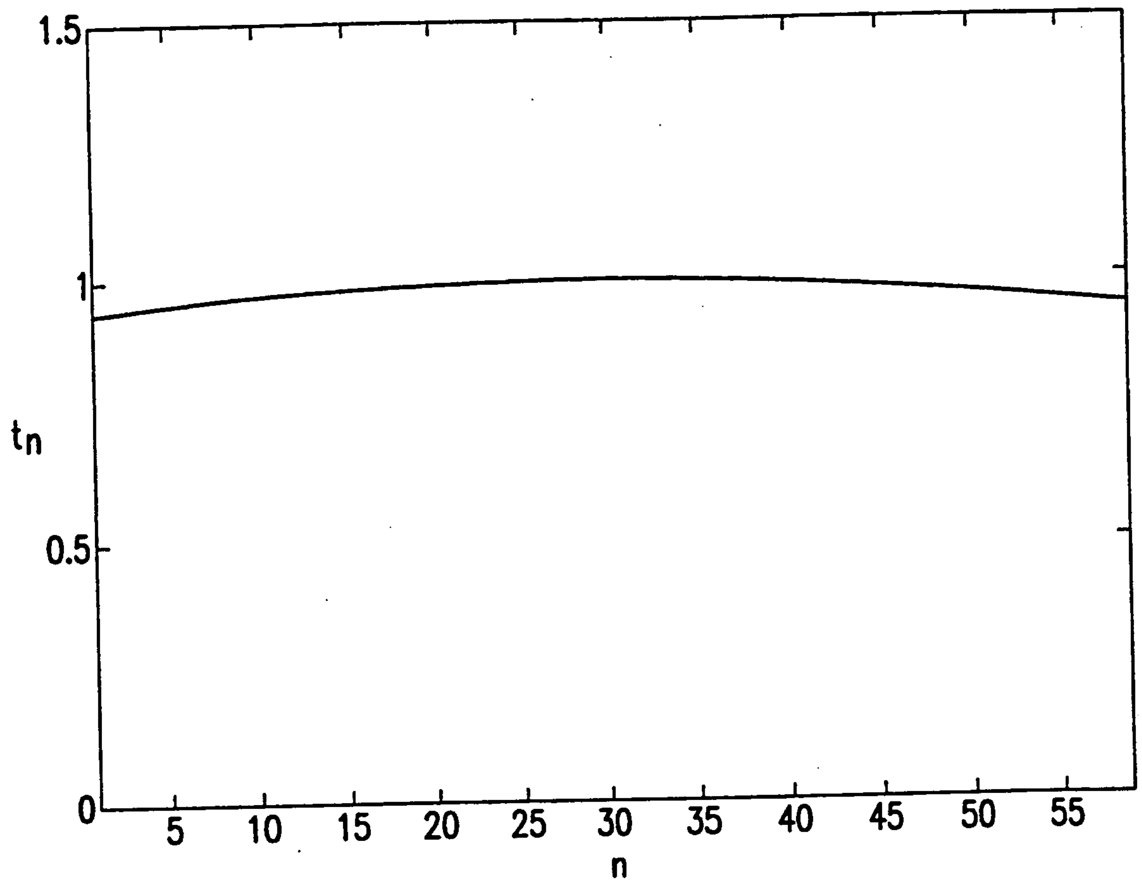

FIG.12

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/00836

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02B5/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 410 431 A (SOUTHWELL WILLIAM H) 25 April 1995 see column 3, line 60 - line 68 see column 4 see column 5, line 1 - line 45 see figures	1,6,7, 11,15, 20,21,23
X A	US 4 958 892 A (JANNSON TOMASZ P ET AL) 25 September 1990 see column 3, line 29 - line 56 see column 6, line 25 - line 36 see figures 1,4D,10A-10C	1,6,7, 15,20,21 10,22
X	FR 2 658 619 A (MEGADEMINI TAOUFIK) 23 August 1991 see abstract see figure 1	1,15

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 April 1999	23/04/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Ward, S

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INTERNATIONAL SEARCH REPORT

Inter. ...nal Application No
PCT/US 99/00836

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 360 659 A (ARENDS CHARLES B ET AL) 1 November 1994 see column 6, line 33 - line 68 see column 7, line 1 - line 3 see figure 2 -----	1,6,7, 15,20,21

1

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inter. ..nal Application No
PCT/US 99/00836

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 5410431	A	25-04-1995	NONE		
US 4958892	A	25-09-1990	NONE		
FR 2658619	A	23-08-1991	NONE		
US 5360659	A	01-11-1994	WO	9428446 A	08-12-1994